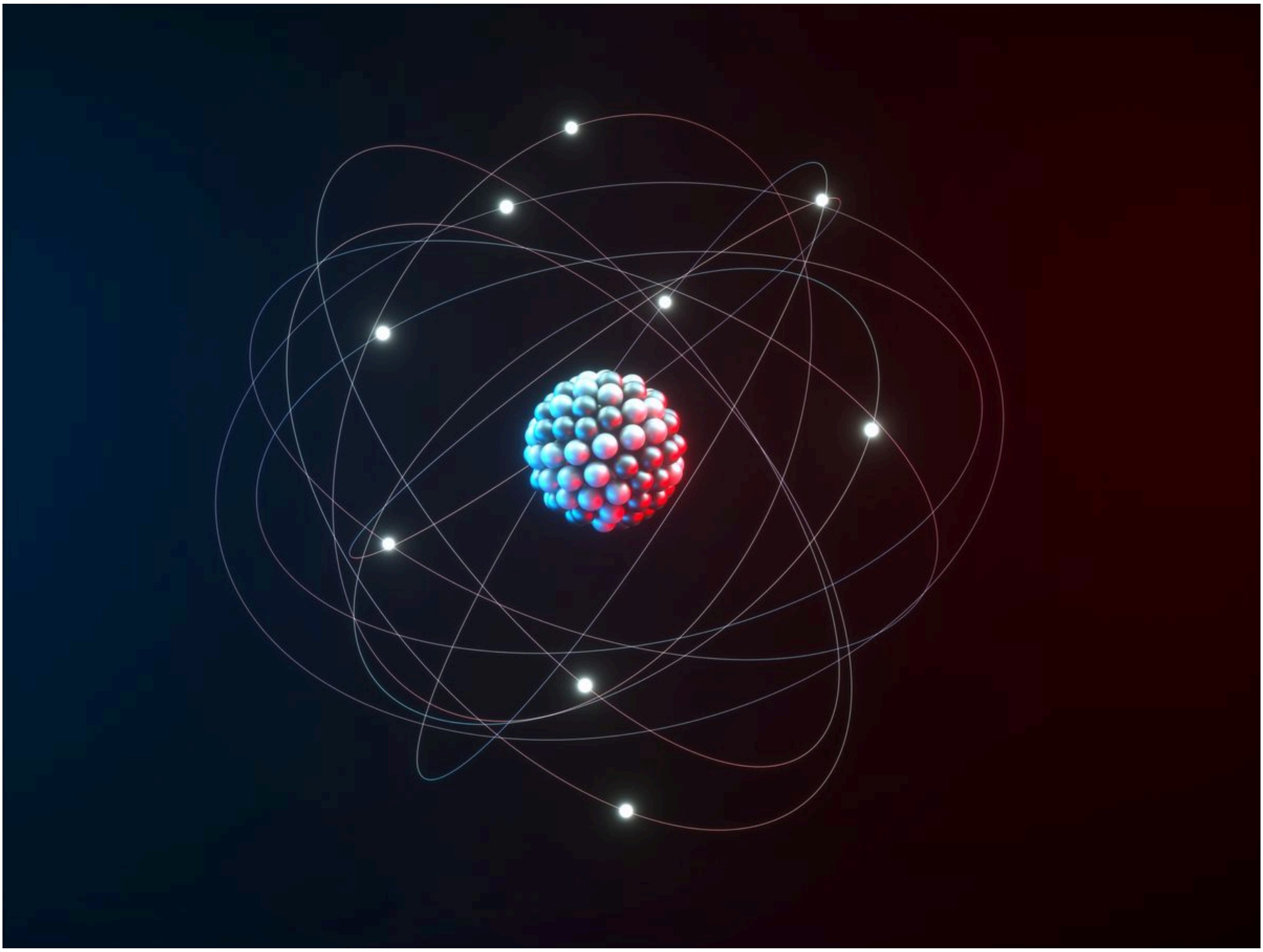
Science > Physics

# Surprise! Protons Contain a Subatomic Particle That's Heavier Than the Proton Itself

**But when the charm quark is present, it still only accounts for around half of the proton's mass. How can that be?**

BY ROBERT LEA PUBLISHED: AUG 30, 2022 2:11 PM EDT



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- New research shows that protons contain intrinsic charm quarks.
- This is despite the fact that **subatomic** charm quarks are about 1.5 times more massive than the proton, itself.

- When charm **quarks** are present, they carry about half of the proton's mass.

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Protons are particles that exist in the nucleus of all **atoms**, with their number defining the elements themselves. Protons, however, are not fundamental particles. Rather, they are composite particles made up of smaller subatomic particles, namely two "up quarks" and one "down quark" bound together by force-carrying particles (bosons) called "gluons."

This structure isn't certain, however, and quantum physics suggests that along with these three quarks, other **particles** should be "popping" into and out of existence at all times, affecting the mass of the proton. This includes other quarks and even quark-antiquark pairs.

Indeed, the deeper scientists have probed the structure of the **proton** with high-energy particle collisions, the more complicated the situation has become. As a result, for around four decades, physicists have speculated that protons may host a heavier form of quark than up and down quarks called "intrinsic charm quarks," but confirmation of this has been elusive.

Now, by exploiting a high-precision determination of the quark-gluon content of the proton and by examining 35 years' worth of data, particle physics data researchers have discovered evidence that the proton does contain intrinsic **charm quarks**.

What makes this result more extraordinary is that this flavor of quark is one-and-a-half times more massive than the proton itself. Yet when it is a component of the proton, the charm quark still only accounts for around half of the composite particle's mass.

## The Weirdness of Quantum Mechanics

This counter-intuitive setup is a consequence of the weirdness of **quantum mechanics**, the physics that governs the subatomic world. This

requires thinking of the structure of a particle and what can be found within it as probabilistic in nature.

“There are six kinds of quarks in nature, three are lighter than the proton [up, down, and strange quarks] and three are heavier [charm, up, and down quarks],” Stefano Forte, NNPDF Collaboration team leader and professor of theoretical Physics at Milan University, tells the **Nature Briefing podcast**. “One would think that only the lighter quarks are inside the proton, but actually, the laws of quantum physics allow also for the heavier quarks to be inside the proton.”

Forte—the lead author of a **paper** published earlier this month in the journal *Nature,* describing the research—and his team set out to discover if the lightest of these heavier quarks, the charm quark, is present in the proton.

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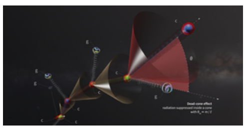

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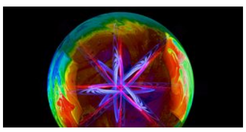

**Physicists Just Found a New Elementary Particle**

When the **Large Hadron Collider** (LHC) and other particle accelerators smash protons against each other (and other particles, like electrons) at high energies, what emerges is a shower of particles. This can be used to

“reconstruct” the composition of the original particle and the particles that comprised it, collectively known as “partons.”

Each of these partons carries away a portion of the overall momentum of the system—the momentum distribution—with this share of momentum known as the momentum fraction.

Forte and colleagues fed 35 years of data from particle accelerators, including the world’s largest and most powerful machine of this kind, the LHC, to a computer **algorithm** that pieces proton structure back together by looking for a “best fit” for its structure at high-energies. From here, the team calculated the structure for the proton when it is at rest.

This resulted in the first evidence that protons do indeed sometimes have charm quarks. These are labeled “intrinsic” because they are part of the proton for a long time and are still present when the proton is at rest, meaning it doesn’t emerge from the high-energy interaction with another particle.

“You have a chance, which is small but not negligible, of finding a charm quark in the proton, and when you do find one, it so happens that that charm quark is typically carrying about half of the proton mass,” Forte says on the podcast. “This is quantum physics, so everything is probabilistic.”

## The “Intrinsic” Charm Quark Scenario

Romona Vogt is a high-energy physicist at Lawrence Livermore National Laboratory (LLNL) in California, who wrote a “News and Views” **piece** for *Nature* to accompany the new research paper.

She explains to *Popular Mechanics* how charm quarks could be connected to proton structure and how the intrinsic charm quark scenario differs

from the standard scenario that sees protons comprised of just two up and one down quarks joined by **gluons**.

“Charm quarks come in quark-antiquark pairs in both the standard scenario and the intrinsic charm one,” Vogt says. “In the standard scenario, a gluon radiates this pairing during a high-energy interaction. Because of the charm quark’s mass, it is too heavy to be part of the ‘sea’ of light up, down, and strange quarks.”

This means the charm quark doesn’t have a large role when physicists calculate the standard parton momentum distribution functions until momentum reaches a threshold above mass.


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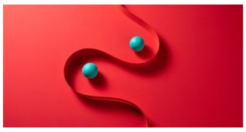

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“That’s very different from the intrinsic charm scenario where the charm distribution carries a large fraction of the proton momentum,” Vogt adds. “Because in the intrinsic charm quark scenario, the quark-antiquark pair is attached to more than one of the up and down quarks in the proton they travel with. That’s why the charm quarks appear at large momentum fractions.

“The proton is more or less ‘empty’ in this scenario or has a small size configuration because the proton is just up, up, down quarks and charm quark pairs with no other quarks at low momentum fractions in the minimal model of intrinsic charm.”

Vogt suggests that the NNPDF Collaboration's results could lead other researchers to ask if other quarks could play a role in the composition of protons.

"One question these findings might raise is whether or not there are other intrinsic quark scenarios, like intrinsic bottom and intrinsic strangeness," she says.

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Robert Lea is a freelance science journalist focusing on space, astronomy, and physics. Rob's articles have been published in *Newsweek*, *Space*, *Live Science*, *Astronomy* magazine and *New Scientist*. He lives in the North West of England with too many cats and comic books.